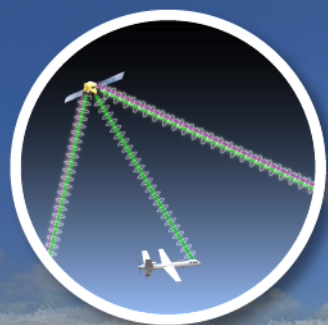




Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

Detect and Avoid



UAS INTEGRATION IN THE NAS

Jay Shively
DAA Sub-Project Manager



Outline

Present:

- UAS Integration into the NAS
- RTCA SC 228 MOPS and Autonomy
- ICAO RPAS Panel and Autonomy

Future:

Single operator control of multiple A/C

Playbook

Human-Autonomy Teaming

Patterns

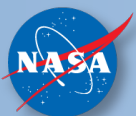
HAT Model



Full UAS Integration Vision of the Future

Manned and unmanned aircraft will be able to routinely operate through all phases of flight in the NAS, based on airspace requirements and system performance capabilities.





UAS-NAS Phase 2

Project Organization Structure

PROJECT OFFICE
LEVEL

Project Leadership

Project Manager (PM) Laurie Grindle, AFRC
Deputy PM Robert Sakahara, AFRC
Deputy PM, Integration Davis Hackenberg, AFRC
Chief Engineer William Johnson, LaRC

Project Support: Project Planning & Control

Lead Resource Analyst April Jungers, AFRC
Resource Analysts Winter Preciado, AFRC

Warcquel Frieson, ARC
Julie Blackett, GRC
Pat O'Neal, LaRC
Irma Ruiz, AFRC
Jamie Turner, AFRC
Lexie Brown, AFRC
Sarah Strahan, AFRC

Scheduler
Risk Manager
Change/Doc. Mgmt
Admin
AFRC

Project Support: Technical

Staff Engineer Dan Roth, AFRC
Systems Eng Lead TBD, TBD

SUBPROJECT LEVEL

Command and Control (C2)

Subproject Manager
Mike Jarrell, GRC
Subproject Technical Lead
Jim Griner, GRC

Detect and Avoid (DAA)

Subproject Manager
Jay Shively, ARC
Subproject Technical Leads
Confesor Santiago, ARC; Lisa Fern, ARC; Tod Lewis, LaRC

Integrated Test & Evaluation

Subproject Manager
Heather Maliska, AFRC
Subproject Technical Leads
Jim Murphy, ARC; Sam Kim, AFRC

ELEMNET/
TWP LEVEL

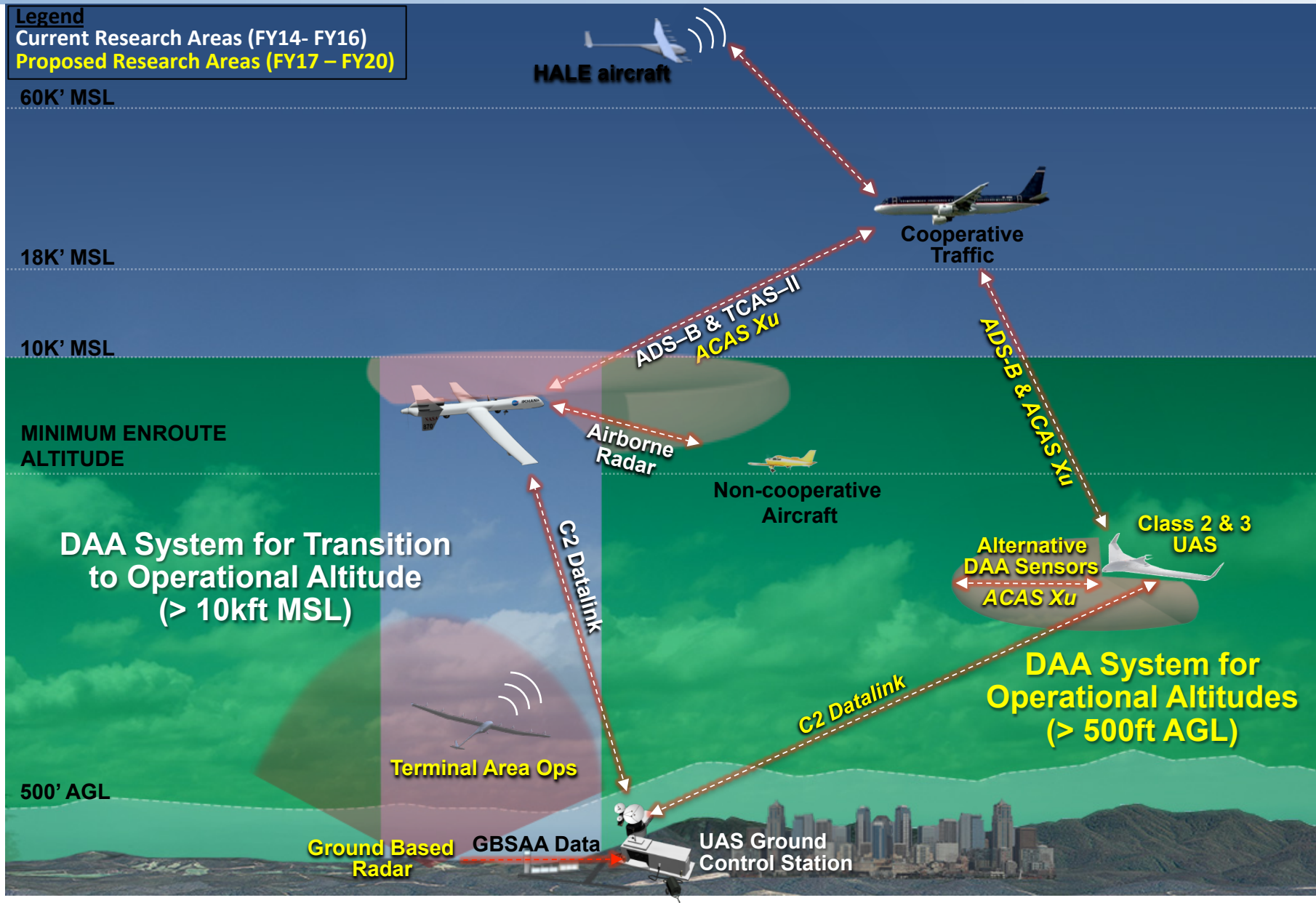
Technical Work Packages (TWP):
Terrestrial Extensions, Ka-band
Satcom, Ku-band Satcom, C-band
Satcom

Technical Work Packages (TWP):
Alternative Surveillance, Well Clear,
ACAS Xu, External Collaboration,
Integrated Events

Technical Work Packages (TWP):
Integration of Technologies into
LVC-DE, Simulation Planning and
Integration, Integrated Flight Test



DAA Operational Environments





Status

- Phase I MOPS RTCA SC- 228 complete and published (March, 2017)
 - Transition to Class A airspace
 - DAA MOPS
 - On-board RADAR MOPS
 - C2 Terrestrial Radio MOPS
- Phase 2 (2021)
 - Operation in Class C, D
 - Terminal Area Operations
 - Low SWAP A/C, sensors
 - GBSAA



General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to **see and avoid** other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless **well clear**.

Piloted “see and avoid” = UAS “detect and avoid”

Pilots vision replace by sensors (on- or off- board or both)

Pilot judgment of well clear = mathematical expression of well clear

Horz Miss Distance = 4000ft; Vert Miss Distance = 450ft;
modTau = 35sec; DMOD = 4000ft



Two Functions:

1) Maintain well clear

- 1) See and avoid

2) Collision Avoidance

- 1) TCAS
- 2) ACAS-Xu

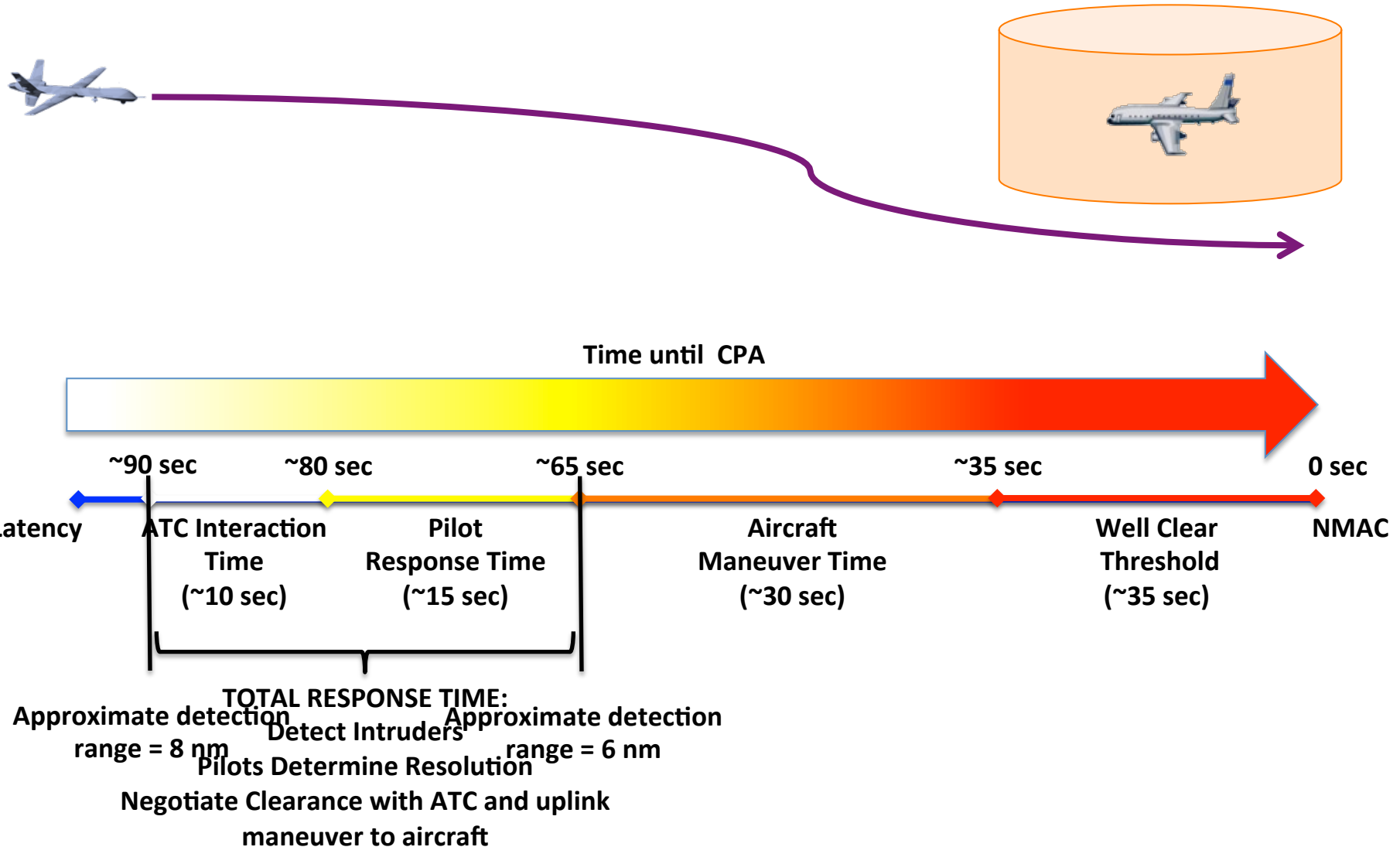


Background

- An early critical question for the Phase I MOPS for DAA systems was what, if any, level of DAA maneuver guidance would be required to support acceptable performance on maintaining well clear?
- Phase I MOPS assumptions specify that the pilot in command will execute maneuvers to remain well clear
 - i.e., No automatic/autonomous DAA capability
- Display types given level/type of maneuver guidance:
 - **Informative**: Provides essential information of a hazard that the remote pilot may use to develop and execute an avoidance maneuver. No maneuver guidance automation or decision aiding is provided to the pilot
 - **Suggestive**: Automation provides a range of potential resolution maneuvers to avoid a hazard with manual execution. An algorithm provides the pilot with maneuver decision aiding regarding advantageous or disadvantageous maneuvers
 - **Directive**: Automation provides specific recommended resolution guidance to avoid a hazard with manual or automated execution. An algorithm provides the pilot with specific maneuver guidance on when and how to perform the maneuver









Draft MOPS Informed by HITLs: Surveillance Range





Alerting

Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Time to Loss of Well Clear	Aural Alert Verbiage
	TCAS RA	<ul style="list-style-type: none"> Immediate action required Comply with RA sense and vertical rate Notify ATC as soon as practicable after taking action 	*DMOD = 0.55 nmi *ZTHR = 600 ft *modTau = 25 sec	0 sec (+/- 5 sec) (TCPA approximate: 25 sec)	"Climb/Descend"
	DAA Warning Alert	<ul style="list-style-type: none"> Immediate action required Notify ATC as soon as practicable after taking action 	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now" x2
	Corrective DAA Alert	<ul style="list-style-type: none"> On current course, corrective action required Coordinate with ATC to determine an appropriate maneuver 	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
	Preventive DAA Alert	<ul style="list-style-type: none"> On current course, corrective action should not be required Monitor for intruder course changes Talk with ATC if desired 	DMOD = 0.75 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
	Guidance Traffic	<ul style="list-style-type: none"> No action required Traffic generating guidance bands outside of current course 	Associated w/ bands outside current course	X	N/A
	None (Target)	<ul style="list-style-type: none"> No action required No coordination required 	Within surveillance field of regard	X	N/A

* These values show the Protection Volume (**not well clear volume**) at MSL 5000-10000ft (TCAS Sensitivity Level 5) 11



DAA Phase 1 MOPS

Autonomous CA is **optional**.

Manufacturers can, if desired, automate collision avoidance – much as Airbus has automated TCAS in the A380.

Autopilot mode to execute the Resolution Advisory.

No action for a traffic advisory.

Autonomous Maintain Well Clear (MWC) function is out of scope. Partly because the solution is **suggestive**.

Phase 2 – closure rates are slower, but A/C are closer, aircraft are less agile – timelines may dictate auto-DAA. Initial study of the trade space (OSU-Woods).



RPAS Manual on Remotely Piloted Aircraft (RPAS) Doc 10019

Autonomous aircraft: An unmanned aircraft that does not allow pilot intervention in the management of the flight.

Autonomous Operation: An operation during which a remotely piloted aircraft is operating without pilot intervention in the management of the flight.

and

the *RPAS Manual on Remotely Piloted Aircraft (RPAS)* restricts the scope to exclude “autonomous aircraft and their operations ...”



However,

Lost link operations, by definition, are operating without pilot intervention (i.e., pilot out of the loop, section 2.13). Therefore, based on the descriptions (section 2.1) and the restriction in scope, **lost link operations are excluded** from the RPAS panel scope. However, these operations are discussed in chapters 4, 8, 9, 10, 11 and 14 of the RPAS Manual.

The ICAO definition of autonomous operations inadvertently excludes lost link operations.



Automation Table

Ability of pilot to intervene

System Characteristic	Pilot can intervene	Pilot can't intervene (lost link)	Pilot can't intervene (design)
Deterministic	Automation	Automation*	Automation
Stochastic	HAT	Autonomy	Autonomy

ICAO: Automation is in scope, Autonomy is out of scope.

* Current lost link.



Multi-dimensional nature

- LOA
 - Sheridan
 - Parasuraman, Wickens and Sheridan
- Aviation Systems
 - Aviate
 - Navigate
 - Communicate
- Phase of flight
 - T.O.
 - En route
 - Approach
 - Landing

Waypoint Navigation:

RPAS xx is automated at level xx, in nav, for the en route phase.



Future

Single operator control of multiple UAS

DoD – AFRL “Heterogeneous-UAS Integration in a single-operator VSCS Environment (HIVE)”

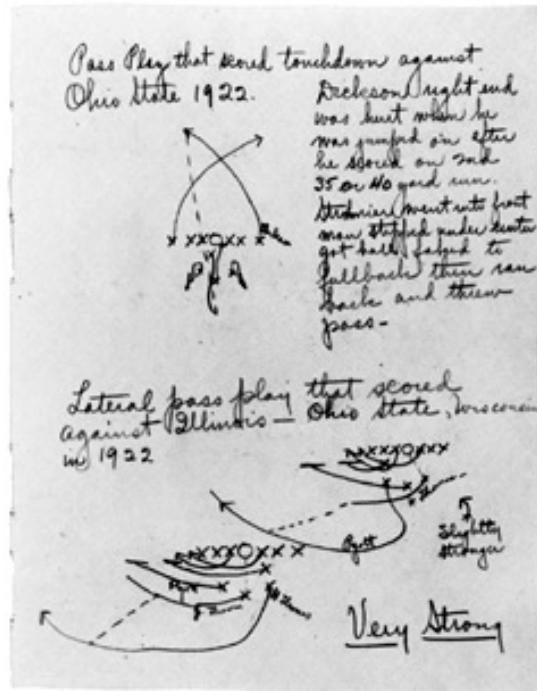
UAS EXCOM Science and Research Panel’s (SARP) - Workshop on multiple UAS controlled by a single operator, June 27 & 28.

Boeing – “don’t see a business model without it.”

Supervisory control – a step before network management (UTM).



Delegation Control: Playbook[®]



- Delegation: one way humans manage supervisory control with heterogeneous, intelligent assets
- Playbook[®]: one's means of delegation
- Plays: analogous to football
 - Quick commands – complex actions
- A Play provides a framework
 - References an acceptable range of plan/behavior alternatives
 - Requires shared knowledge of domain Goals, Tasks and Actions
 - Supervisor can further constrain/stipulate
- Potentially facilitates intuitive cooperative control of Unmanned Systems



Levels of Automation Simulation

Example: Prosecute Target

Tools:

Arm laser → Lase target → Send coordinates to weaponized UAV → Toggle UAVs → Arm missile → Fire

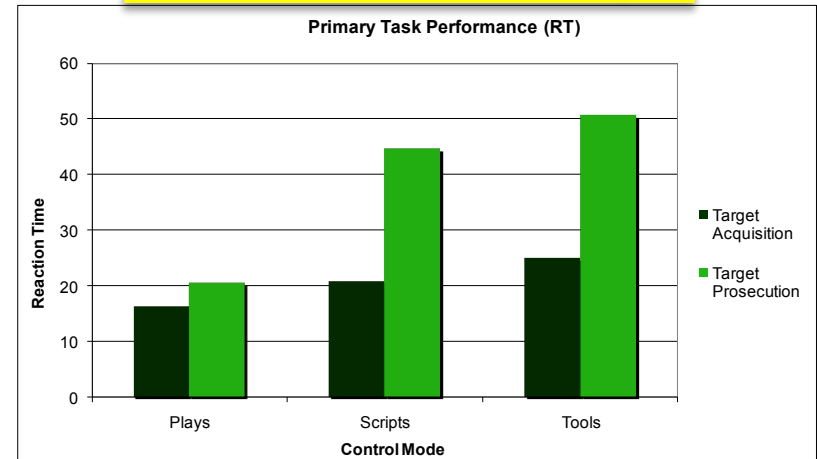
Scripts:

Select 'Lase' script → Toggle UAVs → Arm weapons → Fire

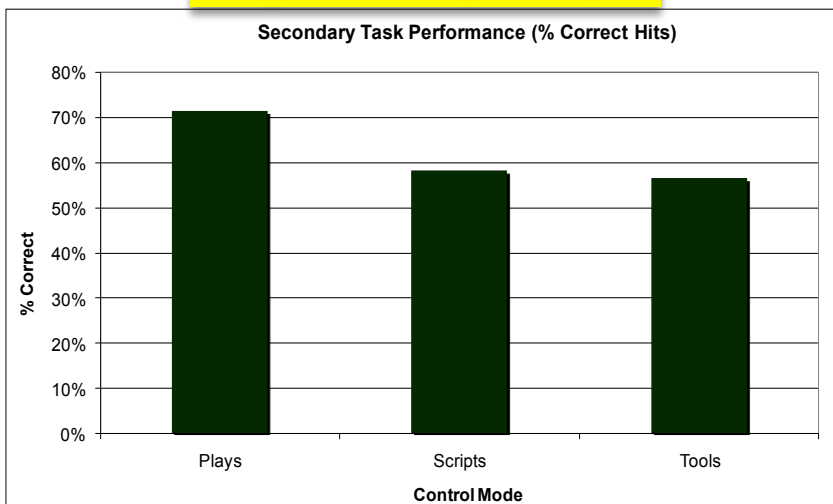
Plays:

Select 'Prosecute Target' play → Fire

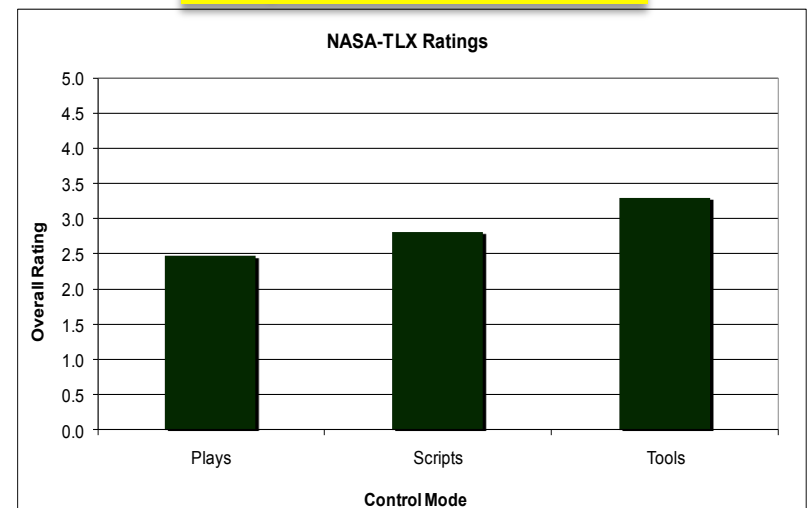
Shorter Reaction Time for Plays



Higher Accuracy for Plays



Plays had lower workload





Manned-Unmanned Teaming: MUM

**Level IV Control:
Control of Payload and Vehicle
Excluding Take-off and Landing**



**Extend to simultaneous control of
multiple heterogeneous UAS**





Manned-Unmanned Teaming: MUM

Goals:

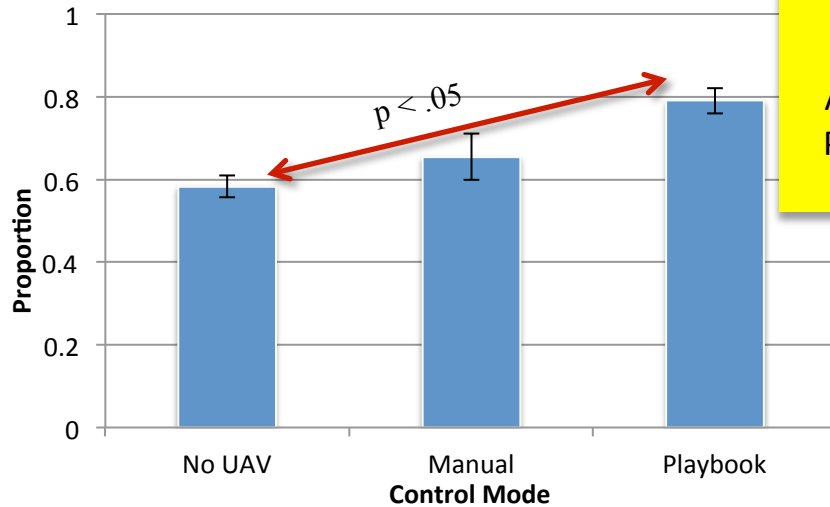
- Apply Playbook[®] methodology and DelCon lessons learned to helicopter cockpit; Test in simulation
- Increase capability and efficiency of UAS control by helicopter pilots
- Supervisory control of multiple, heterogeneous UAS
- Develop infrastructure and lay foundation for later efforts



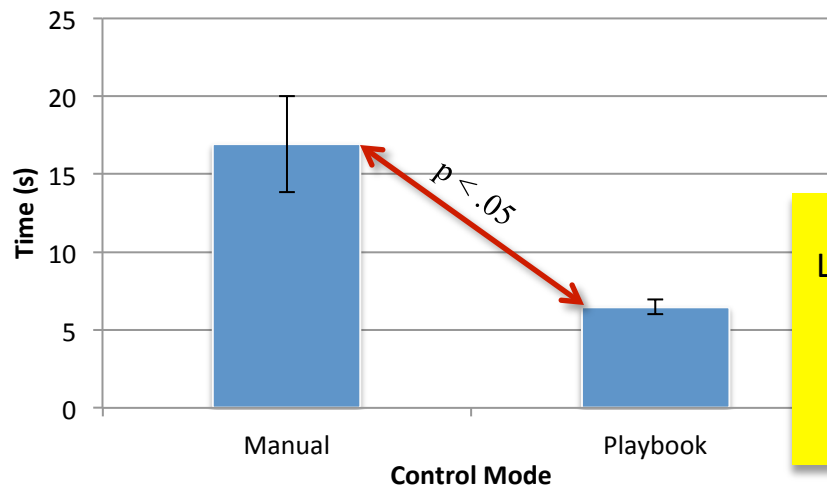


Results

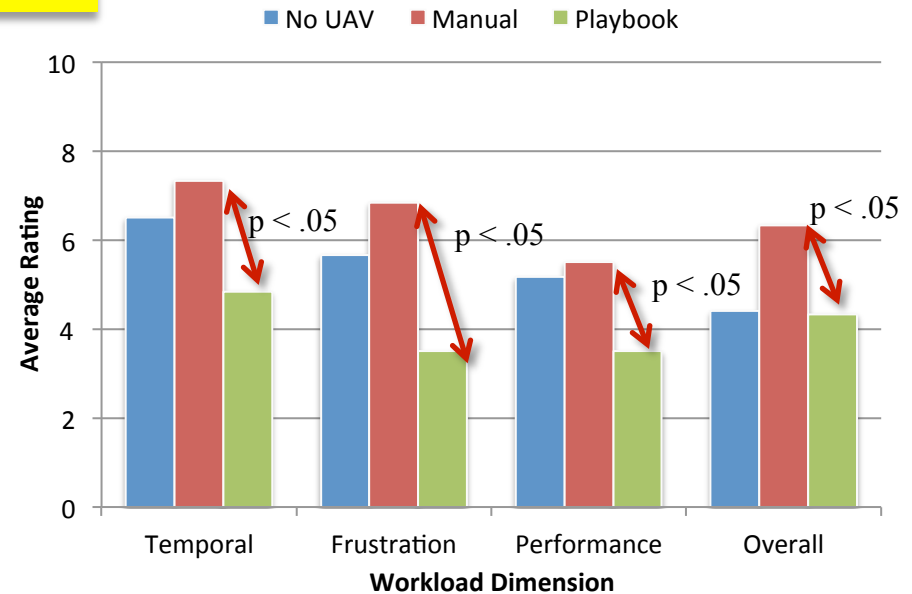
Proportion of Targets Marked by Control Mode
(Out of Total Possible)



UAS Route Planning Time by Control Mode



NASA – TLX Ratings



Lower workload for Playbook on several dimensions



Flight Demonstration 2009

Ft. Ord CA, 23 APR 2009

Goal:

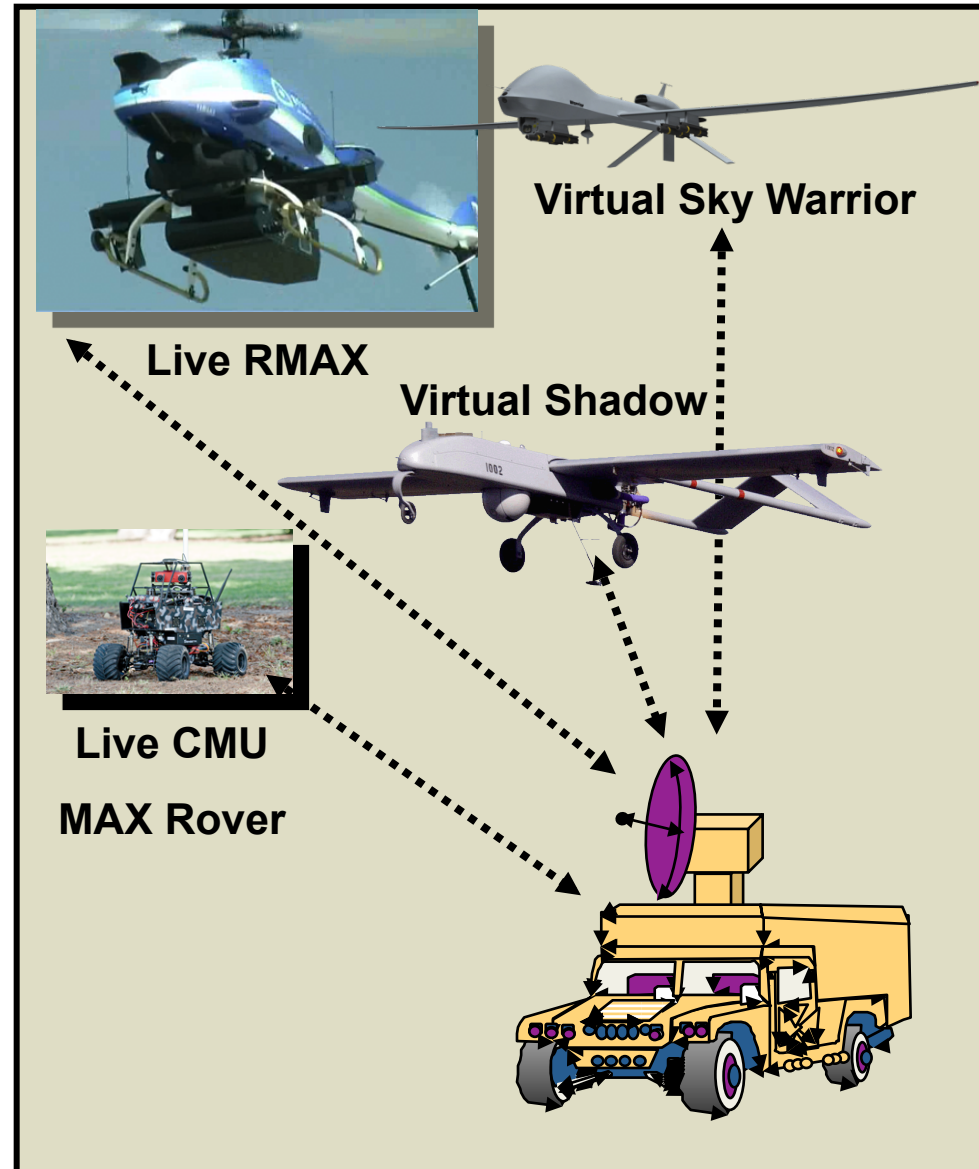
- Demonstrates initial proof of concept of Delegation Control (Playbook) in flight – supervisory control of multiple air/ground assets in MOUT Scenario

Method:

- Live/Virtual Demo – Controlling RMAX, CMU MAX Rover and 2 virtual UAS with Delegation Control
- Voice RGN Control (USAF)

Features:

- Delegation control human-machine interface supports control and monitoring 4 payloads
- Automation Transparency
- Live UGV-UAV coordination for slung load drop
- Reduced operator workload/high situation awareness





Flight Demonstration 2011

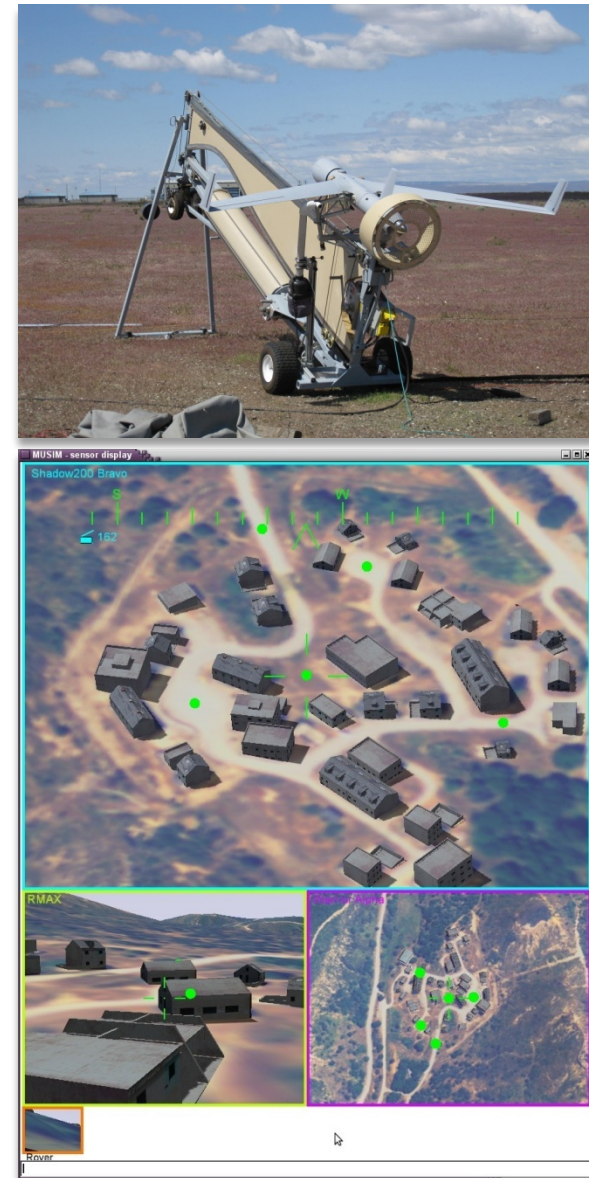
Ft. Hunter-Liggett CA, 19 May 2011

Purpose:

- Build on previous simulations and flight test examining single operator control of multiple heterogeneous ground/air unmanned systems through delegation control employment
 - Operator performance data collection/workload assessments
 - Heterogeneous flight assets: **Boeing Scan Eagle** and **Yamaha RMAX**; two virtual UAS
 - Testing in operationally relevant mission scenarios
 - Multi-sensor cross-cue in support of both targeting and convoy support
- Army AFDD/Boeing CRADA

Key Objective:

- Develop and test DelCon **Top Priority Plays**; route recon, convoy support, troops in contact





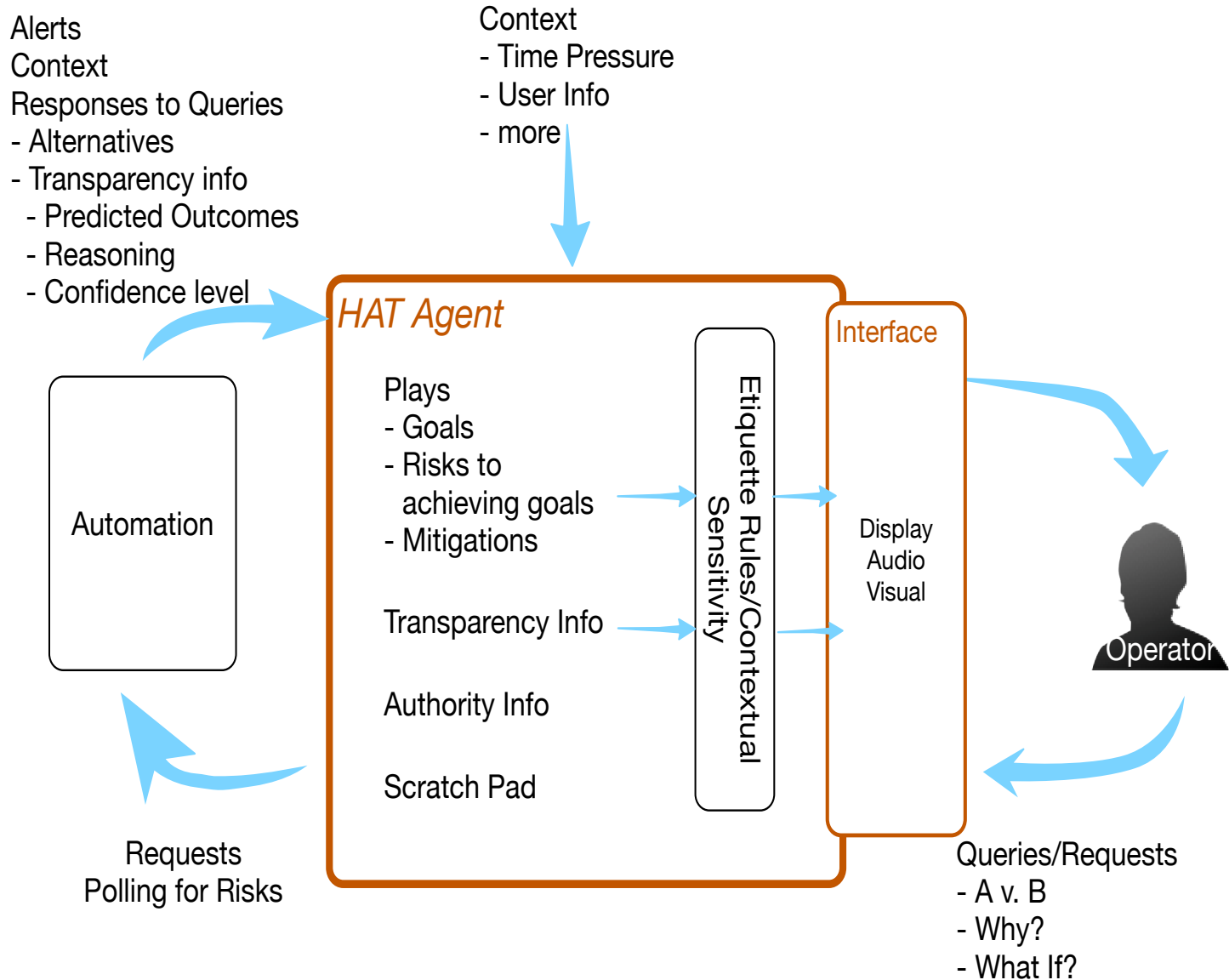
Supervisory Control Summary

Demonstrated in numerous simulations and flight tests (even NOPE).

- AFRL – Base security, UAS ground station
- RCO – Dispatch, cockpit
- HAT



HAT Agent





Problems with Automation

- Brittle
 - Automation often operates well for a range of situations but requires human intervention to handle boundary conditions (Woods & Cook, 2006)
- Opaque
 - Automation interfaces often do not facilitate understanding or tracking of the system (Lyons, 2013)
- Miscalibrated Trust
 - Disuse and misuse of automation have lead to real-world mishaps and tragedies (Lee & See, 2004; Lyons & Stokes, 2012)
- Out-of-the-Loop Loss of Situation Awareness
 - Trade-off: automation helps manual performance and workload but recovering from automation failure is often worse (Endsley, 2016; Onnasch, Wickens, Li, Manzey, 2014)



HAT Solutions to Problems with Automation

- Brittle
 - **Negotiated decisions** puts a layer of human flexibility into system behavior
- Opaque
 - Requires that systems be designed to be **transparent**, present **rationale** and **confidence**
 - Communication should be in terms the operator can easily understand (**shared language**)
- Miscalibrated Trust
 - Automation **display of rationale** helps human operator know when to trust it
- Out-of-the-Loop Loss of Situation Awareness
 - **User directed interface**; adaptable, not adaptive automation
 - Greater interaction (e.g., **negotiation**) with automation reduces likelihood of being out of the loop



Legend



Human Operator



Intelligent / Cognitive Agent



Automated Tools



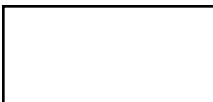
Communication Only



Supervisory Relationship



Cooperative Relationship



Co-location (e.g., onboard an airplane, in ground station)

Both imply
***bi-directional
information flow,***
usually using
automated tools



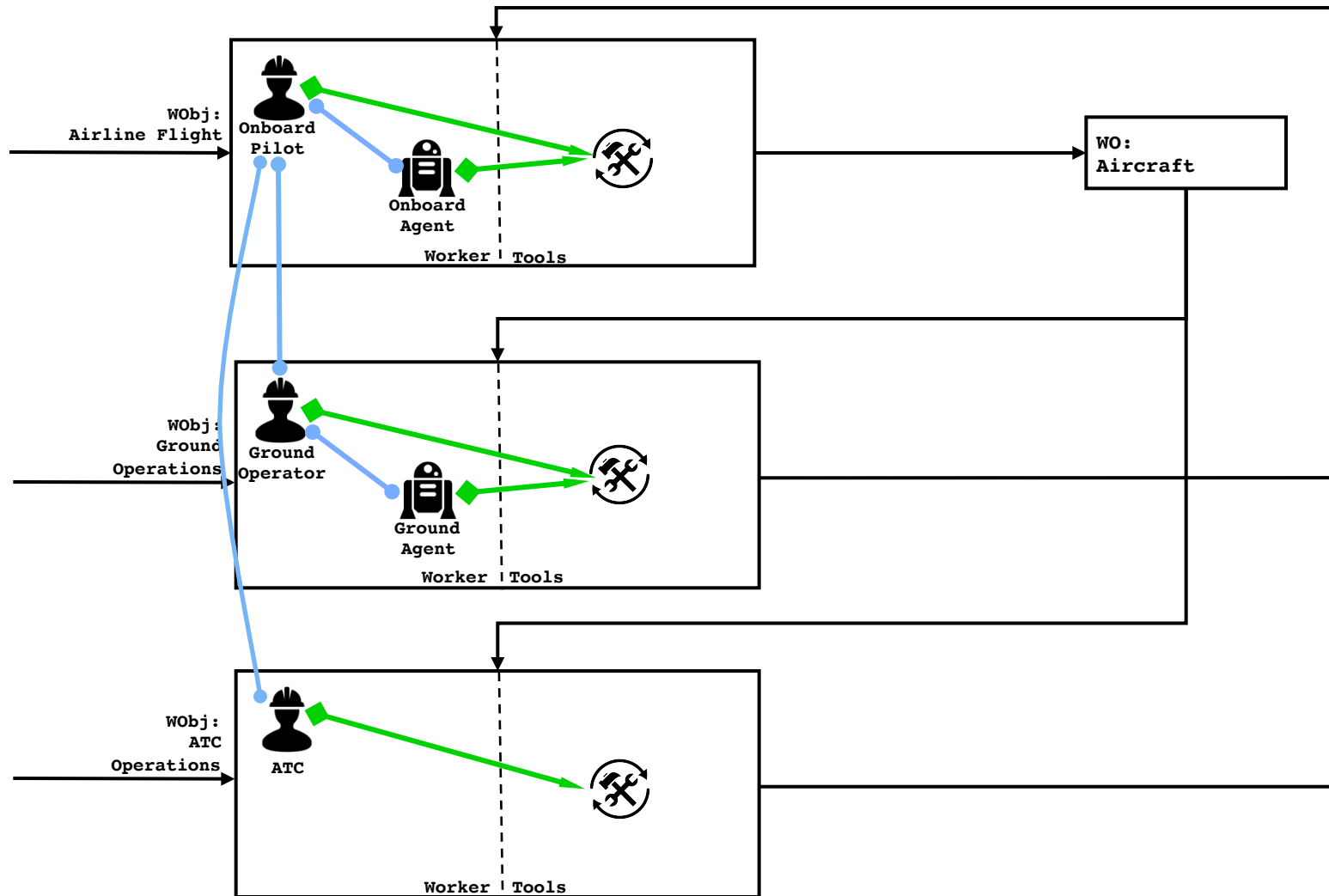
RCO Use-Case

FLYSKY12 is en route from SFO to BOS. There is one POB and a dispatcher flight following.

- Onboard automation detects fuel imbalance and alerts POB and dispatcher.
- POB requests automation diagnose fuel imbalance. Automation reports to POB a leak in left tank.
- POB requests that agent manage fuel. Agent opens the cross feed and turns off the pumps in the right side to draw fuel from the left.
- POB contacts dispatch about need to divert.
- Dispatcher requests divert planning from dispatch automation.
- Dispatcher uplinks flight plan to POB. POB inspects the flight plan and agrees.
- POB requests agent coordinate divert with ATC. Agent reports divert is approved. POB tells agent to execute.

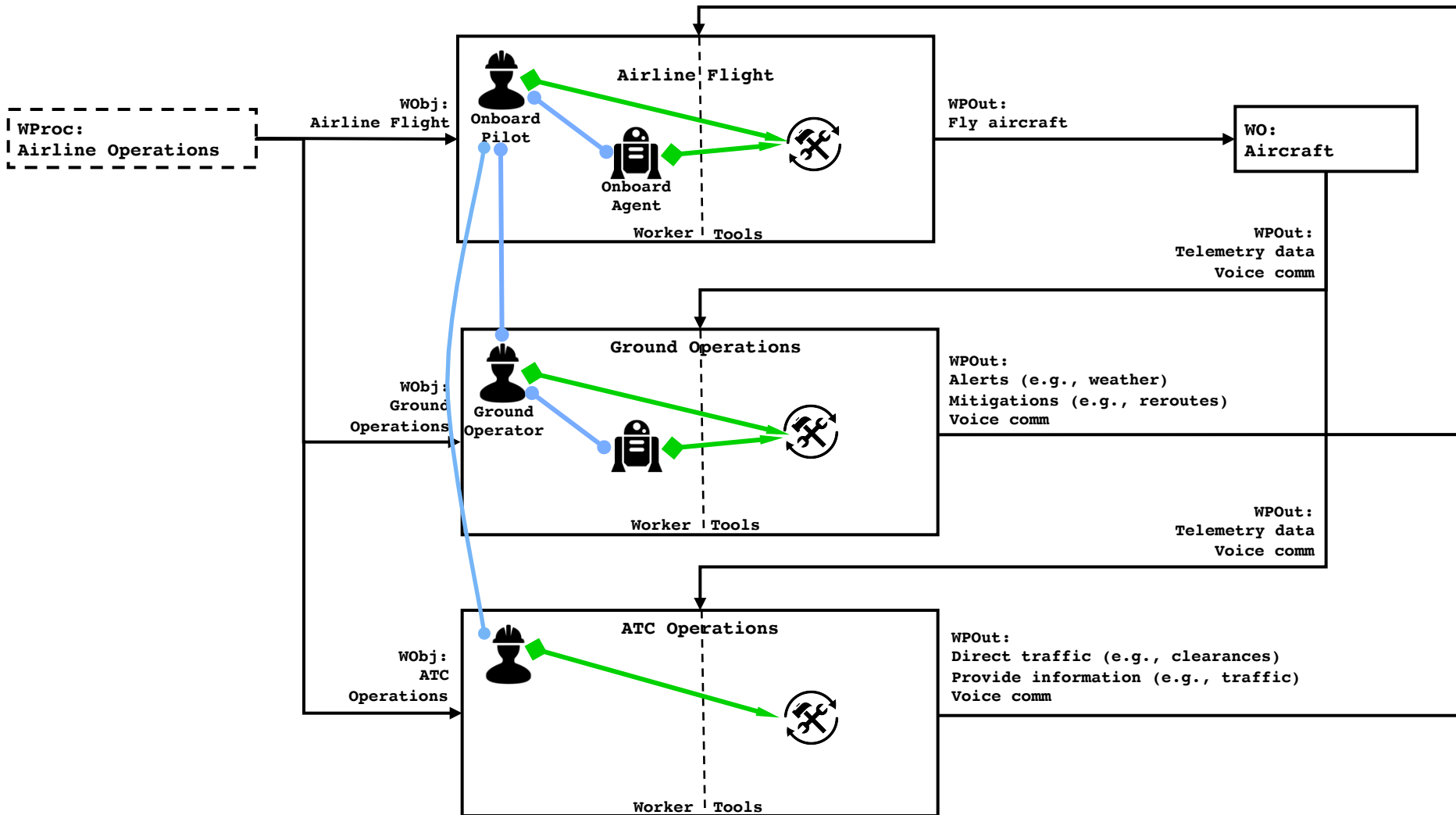


Top-Level Actor Relationships





Top-Level System Work





Summary

- Autonomy
 - Not in today's "approved" UAS
 - Words Matter
 - ICAO
- Business case for single operator supervisory control of multiple UAS
 - Playbook delegation is one successful method
- HAT
 - Cooperative agent with knowledge of work domain
 - Shared world knowledge
 - Can we extended to network supervision